Marine Meteorological Measurements from the USCG Polar Class Icebreakers.

Dr. Phil McGillivary
US Coast Guard Icebreaker Science Liaison

The USCG operates three icebreakers for high latitude logistics and research for the US government and all federal agencies, with the ships based out of Seattle, Washington. These vessels include two 399' Polar class icebreakers, *Polar Star* (NBTM) and *Polar Sea* (NRUO), which are the principal ships tasked with the annual mission to break an ice channel in to the US' McMurdo Station in the Ross Sea, Antarctica, to permit re-supply of the base during the austral summer (northern winter). Typically this mission is carried out by one of the Polar icebreakers, with the second vessel held in reserve. However in the past two years, heavy ice conditions have required the use of two icebreakers, a condition anticipated to persist for the foreseeable future. Normally, one or both of the Polar Class icebreakers also conducts research in the arctic during the northern summer, typically calling at Barrow, Alaska, during their summer missions. A new icebreaker, the 420' *Healy*, began its' mission as an arctic research vessel in 2001. In transiting from the eastern to the western arctic, *Healy* (5LZE) has gone through the Canadian Northwest Passage once, and once transited through the Panama Canal. Future transits of the arctic will likely involve these routes again, as well as periodic transits across the North Pole.

The annual cruise track of the Polar class icebreakers from Seattle to Antarctica to Seattle to Barrow, Alaska, provides them an annual latitudinal range of standard operations greater than any other US research vessels. This

great latitudinal range drives many of the research objectives of meteorological measurements from these ships. Principal research objectives for which marine meteorological measurements from the icebreakers have been or can be used include: 1) high latitude inputs to weather/climate models; 2) satellite calibration/validation of existing and newly launched environmental observing satellites (including taking identical satellite sensor systems aboard the ship); 3) air-sea flux measurements involving elemental budgets, including hydrogen, carbon (as CO2), sulfur, and halogens; 4) correlation of ship sensors with those from radiosondes, Global Ocean Observing System (GOOS) floats, ARGO floats, SOLO floats, and ice buoys, and autonomous underwater vehicles (AUVs) deployed during icebreaker missions; 4) comparison with data from high latitude underwater observatories now existing (e.g., on Little Diomede Island) and planned (the PRIMO observatory in McMurdo Sound, Ross Sea, Antarctica); and, finally, 5) studies of physical and chemical fluxes relating to "ice breeze" phenomena at the edge of pack ice, as well as similar flux studies at leads and polyn'yas in the ice. In the future, high latitude ship-collected marine meteorological data can be useful for several studies proposed to focus on the relation of solar/sunspot maxima to Earth's meteorological fields as well as "space weather" (c.f. CAWES, the 2003-2007 program on Climate And Weather in the Sun-Earth System).

Calibration of the sensors is typical done before and after each scientific cruise. Advantage has been taken of the typical annual ship track to Barrow, Alaska, by including meteorological sensors on the ships identical with those located at the Dept. of Energy ARM site outside Barrow, Alaska, for purposes of sea-truth and instrument inter-calibrations. Additional calibration notes are provided below for certain sensors. The development of self-cleaning sensors would improve sensors' ability to more consistently collect data closer to calibration capabilities, in addition to having specific scientific personnel on board dedicated to ensuring systems are tended and remain fully operational. Relying on shipboard technicians to conduct sensor cleaning and maintenance as an ancillary duty has proven unsatisfactory in the past.

Data management of marine meteorological sensor data is handled via the NOAA SEAS-V scientific computer network software used on the ships. Basic data (e.g., wind speed, direction, pressure) is regularly transmitted every four hours via Inmarsat to the National Ocean Data Center (NODC) . Metadata may be provided by the Coast Guard Marine Science Technicians (MSTs) or by scientific project coordinators for each cruise. Investigators, such as Peter Minnett, have found that a simple examination of basic data to determine sea state, wind velocity and direction in relation to ship speed can allow simple algorithms to simply discard data above certain critical levels for these parameters. Throwing out data collected under questionable conditions is the simplest and best means of data quality control on the Polar Class icebreakers, whose entirely round, unchined hulls give them the apt nickname "Polar rollers". When they roll above a certain level due to combination of wind and seas, it is best to just discard some measured parameters. At the end of each mission, a CD ROM of all data collected during the cruise is provided to scientists involved.

The main marine meteorological parameters on the Polar icebreakers are logged from sensors at a frequency of once per second, with all sensor clocks slaved to a central GPS master clock. Shipboard met sensors include:

Ship background information:

- GPS: Ashtech dGPS system with four GPS sensors at "corners" of ship main superstructure; system has capability of P-code GPS (routinely in use)
- Pitch/Roll Sensors
- Other parameters measured include: relative humidity and barometric pressure
- A shipboard continuous flowing seawater line (from ~4m depth) records temperature and salinity, and has often been used for gas measurements for correlation with meteorological data.

Wind:

- A suite of four standard R.M. Young propeller anemometers (historically certified by the Navy for aircraft operations, as required in support of the two helicopters the Polar icebreakers usually carry) mounted around the ships' main mast at the corners of an attached square platform at a height of ~85' above water level;
- A Handar (Sunnyvale, Ca.) Ultrasonic Anemometer (with heating coil to prevent snow/ice accumulation), mounted on a jack-staff in front of the ship's main mast. Data from the unit are amplified, recorded (in event of power failure), and forwarded by a Keithley Data Logger cabled into the ships' met lab behind the bridge, where they are entered into the ships' Science Data Network. The ultrasonic unit is periodically checked with a Sperry (#09101) hand-held Wind Monitor - NIA/Marine Wind Sensor.

Radiometers:

- Eppley Pyranometer and Eppley Pyrgeometer have both been used mounted on a jack-staff in front of the ship's main mast that is geniculated for lowering forward to permit sensor dome cleaning of stack soot and salt spray.
- MAERI - since 1999 Dr. Peter Minnett's MAERI device (Marine Atmospheric Emitted Radiance Interferometer) has been on the Polar class icebreakers annually both to the Antarctic and in the arctic. On some cruises additional radiometers were deployed for comparison by Dr. Minnett.

Purchase of additional shipboard marine met gear for the Polar icebreakers was planned to include an Yankee Environmental Systems Total-Sky Imager, Rotating Shadow band Radiometer, a Ceilometer, and an Optical Rain Gauge. These purchases were delayed when it was discovered that maintaining this equipment properly was beyond the ships' force capabilities, and there was a lack of demand for data from these sensors by science community members who were the principal funded ship users. Recent requests for additional marine met gear on the Polar Class icebreakers have reinstated interest in all the sensors noted above, as well as aerosol measuring systems including a Cloud Droplet Probe and Single Particle Soot Photometer (Droplet Measurement Technologies, Boulder, Co.). A request for an optical rain gauge is linked to more widespread deployment of acoustic rainfall monitoring sensors on ocean drifters and mooring buoys. Cloud droplet and soot/aerosol data could in future be used to

calibrate/validate aerosol data from the NASA TERRA satellite. A request by NOAA Environmental Technology Lab (ETL) to mount a meteorological flux tower just back of the ships' bow is now also being considered, along with a request for stops near NOAA-maintained met buoys in the tropical Pacific for a 24 hour period during annual transits to allow for inter-calibration with buoy wind and (when present) radiation sensors. Deployment and use of these new sensors and sensor systems can be accommodated where personnel serving as met sensor "minders" are provided by universities or government agencies to participate in cruises to assure the proper maintenance and operation of marine met gear. In the past CO2 sensor systems have been deployed on the Polar icebreakers as part of (and subsequent to) the Southern Ocean Iron Experiment (SOFEX), but required human minders. In the future, similar CO2 and related sensor systems may be part of self-contained instruments designed by the International SeaKeeper Society, which can also be used to correlate with marine met data.

An important value of marine meteorological sensors on the Polar Class icebreakers is to provide data for satellite calibration and validation over the great latitudinal range they cover during their annual transits. Ship wind sensor data can be used for validation of sea winds obtained from the currently operational QuikScat satellite. Calibration/validation of these winds over the sea will soon be of increasing importance as QuikScat winds are about to be incorporated into Navy global operational wind and weather models. In the near future shipboard wind data may be used to calibrate/validate wind data obtained from the NASA SeaWinds sensor on the Japanese ADEOS-II satellite. Currently all three USCG icebreakers have been active in providing sea truth data for ENVISAT, the first satellite to be able to distinguish snow depth as separate from sea ice thickness when sea ice is snow-covered. A radar system similar to that on ENVISAT was mounted on the HEALY in summer of 2001 in the eastern arctic by ENVISAT PI Son Nghiem (NASA JPL). Similarly the icebreakers will be used during the 2003 and subsequent seasons to measure sea ice thickness for calibration/validation of ICESat, launched by NASA in March 2003, and can provide similar data for ice thickness estimates from the MODIS sensors on NASA's AQUA satellite. Atmospheric moisture and aerosols are particularly important aliasing components of satellite remote sensing data, and additional sensor information on these parameters can further broaden the range of satellite calibration and validation information for the new suite of NASA-launched earth-observing satellites.

In summary, the annual cruise tracks of the Polar Class icebreakers, POLAR SEA and POLAR STAR, from 70 North to 70 South latitudes permit collection of high resolution marine meteorology data that can make a significant contribution to a wide range of scientific community interests, as well as global weather and environmental models.